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Title:

# Method and Apparatus of in Situ Measurement and Overlay Error Analysis for Correcting Step and Repeat Lithographic Cameras

Text



Overlay errors can be expressed as a 2-dimensional polynomial series in each of the x- and y-directions. It has been repeatedly observed that the major contributions to these errors in step-and-repeat machines can be described by the linear terms of such series, typically accounting for 80% to 95% of total overlay error, and it has been amply demonstrated in laboratory practice that these errors are indeed correctable by simple machine instructions. The linear overlay errors are, in order of importance: offsets, magnification or stepping, and rotations (including orthogonality). Lithographic cameras when tuned up to practical perfection do not reside long in that state. Errors return with time or use. It has been found experimentally that for the maximum precision of overlay, the magnitude of these errors must be monitored with a frequent schedule. This monitoring is at present accomplished by having a human operator read a considerable number of verniers on a wafer, calculating the errors, and applying the appropriate machine corrections. This process is so slow and subject to human factors as to be impractical in a manufacturing environment. It is the purpose of this article to show how the same results can be achieved automatically and efficiently with minimum human intervention. Further disclosed is the means for an independent audit to verify that the machine executes commands and achieves desired, specified results on the wafer. Implementation of the general working concepts described here will permit an iteratively improving process to a predetermined, specified overlay end-point (ground-rule). We describe the principal techniques using the MANN 4800* system as an illustrative vehicle, while realizing that such principles are general and not limited to this particular machine. We point out that the scheme depends upon the final results that the machine produces on a wafer, as distinguished from some internal references or adjustments within the machine. What we seek to do is to use the apparatus described below to modify the vendor's lithographic camera to permit measurement of overlay errors in situ by the interferometer system inherent in the camera, to digitize such data, pass it via an appropriate I/O interface to the internal computer of the camera or an auxiliary processor to perform the calculations, and to use the results in order to correct the machine. If in place of a product wafer, a fixed standard reference wafer is used as a basis of measurement, and if certain controls in the machine are motorized, a tune-up of the machine becomes possible automatically by closing the loop. On a similar basis, specifications of precision may be entered into the system suitable

for the job to be performed and the system may be made to operate automatically to conform to the specifications or to reject the job as not being within its capability. For example, high precision jobs will undoubtedly require more measurement and checking than those of low precision run on the same machine. The machine itself can make the decision as to how much measuring and adjustment is required to meet specifications. The alterations of the machine are particularly simple to accomplish in the MANN 4800 system, which has been taken as exemplary. We thus proceed here to describe the required modifications. There exists in the MANN 4800 machine a pair of optical microscopes which focus on a pair of standard alignment keys on the wafer. Remove the eyepieces and replace them with a slit in the objective lens image plane. Behind these slits position a pair of photodetectors (photomultiplier (PMT) or photocell) rigidly attached to each other. Connect to each photodetector signal output a suitable analog-to-digital (AiD) box. Electrically trigger the A/D converters from the x- and y-interferometer legs, as detailed below. The digitized signals from these converters are fed to the computer for on-line "Line-Sine" fit and statistical analysis. This is all that is needed for measurement and knowledge of machine corrections. On the first lithographic level of the wafer, close to the standard alignment keys, etch linear marks parallel to the x- and y-axes of the stepper stages, as per Fig. 1 and expanded view of Fig. 2. On the second lithographic level etch similar marks separated from the first set by a distance greater than any conceivable error, say, 3 or 4 microns. These marks are, of course, incorporated in the lithography mask. On the second overlay level there will then appear two marks with a nominal separation distance. The mark-pairs may be scanned across the photodetector-slit combinations by normal x- and y-displacement of the stepping stages, e.g., first in x, then in y. During the x-scan, the A/D boxes are triggered by the x-interferometer leg, and in the y-scan by the y-interferometer leg, triggering occurring at each quarter-wave, for example. There thus results in each digital channel data comprising points on a curve of intensity against position, where the positions are derived from the inherent interferometers of the camera, as seen in Fig. 3, the "Line-Sine" fit is applied to these intensity vs. position curves and from these the uncertainty of the measurements is derived. Hence, the limit of significant numerical interpolation between the measured points is known. Thus, the precision with which threshold crossings are solved is known. If the precision of measured points is greater than required, then the triggering intervals can be increased or the data averaged, and vice-versa. Interpolation and, therefore, the solution from the "zero-crossings" can be brought into any degree of precision within the definite limits set by the temporal drift of the machine over a given time constant. The result, then, from merely two pairs of marks provides enough information to correct for offsets and isotropic dimensional changes. By the addition of a third pair of reference marks on the mask, both anisotropic dimensional changes and an orthogonality in the system can be checked on the wafer. The above follows from the following mathematical considerations. Consider first the case of only four measurements. Let the centroid of the pattern of linear marks be x1, y1, x2, y2, and the differences from nominal distance between these points be Zx1, Zy1, Zx2, Zy2. It is assumed with only 2 points and 4 measurements that any expansions or contractions are isotropic and that the mechanical ways are orthogonal. We have then, in general: $axx + bxy + cx = Zx$ $ayx + byy + cy = Zy$ By hypothesis, $ax = by$ $ay = bx$ In addition, by measurement, $axx1 + bxy1 + cx = Zx1$ (1) $axx2 + bxy2 + cx = Zx2$ (2) $ayx1 + byy1 + cy = Zy1$ (3) $ayx2 +$

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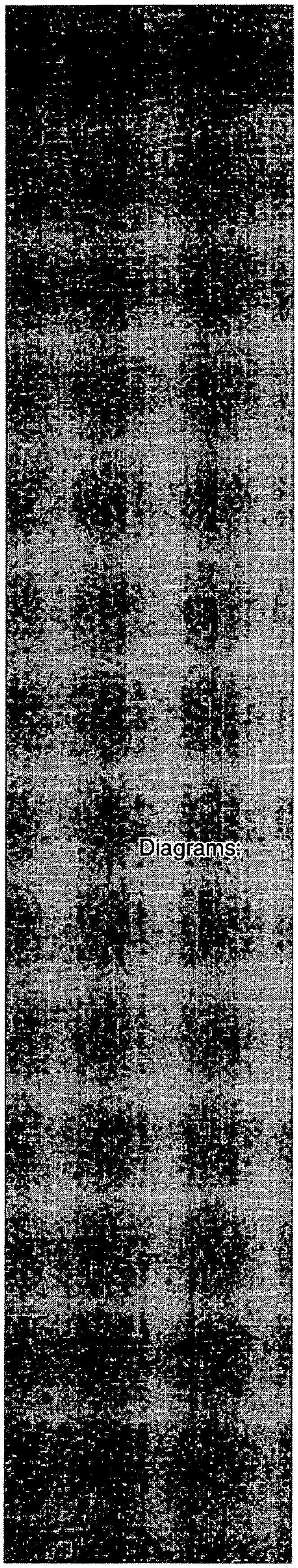


byy2 + cy = Zy2 (4) We can then solve these simultaneous equations for the four independent parameters ax, bx, cx, cy . Physical interpretations are ax represents magnification or stepping error, bx represents rotation, and the c's represent offsets. When three pairs of measuring reference lines are used, the assumptions of isotropicity and orthogonality are abrogated, and separate magnification and rotation measurements are obtained by solution of six independent linear equations. In addition to the solutions, the Line-Sine fit provides a measure of the derivative at the crossing points and, hence, there is a measure of the precision at each point. The measure of precision provides, in turn, the basis for a decision-rule for the amount of measuring which is required to bring the system into satisfying any given set of specifications on overlay. The standard reference lines will diagnostically test the machine per se and reveal departures from the initial set-up condition. Application to processed wafers will reveal then departures from overlay perfection associated with processes. By proliferating measurements over single chips or whole wafers, all the measurements which are normally obtained from only verniers can be obtained from the machine itself without special, off-line measurement equipment or human intervention in the measurement cycle. The advantages are self-evident for both laboratory development and manufacturing production. The applications of the techniques disclosed here are conceivably even more important when lithography is required on a substrate whose distortion is significantly greater than that normally found in silicon. A key feature of this disclosure is the achievement of making the step-and-repeat camera system a "vernier" reader (measurement tool) with all the necessary wafer handling and temperature controls built in, with no physical changes to the operating machine other than, at most, a few solder connections. * Trademark of G.C.A. Corp., Burlington, Mass.

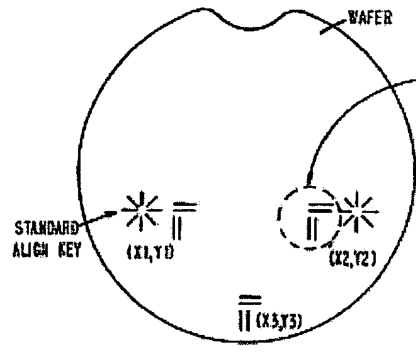


FIG. 1

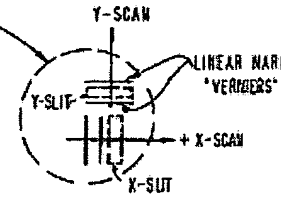


FIG. 2

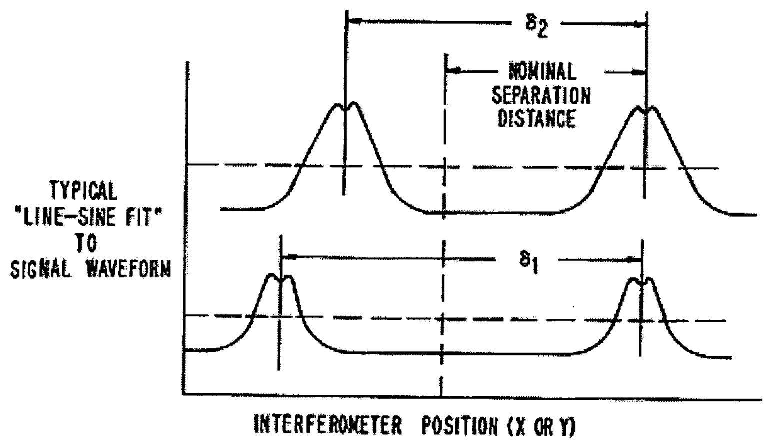


FIG. 3

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